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# Hydrogen Technology Research Program

# Annual Review 1990/91

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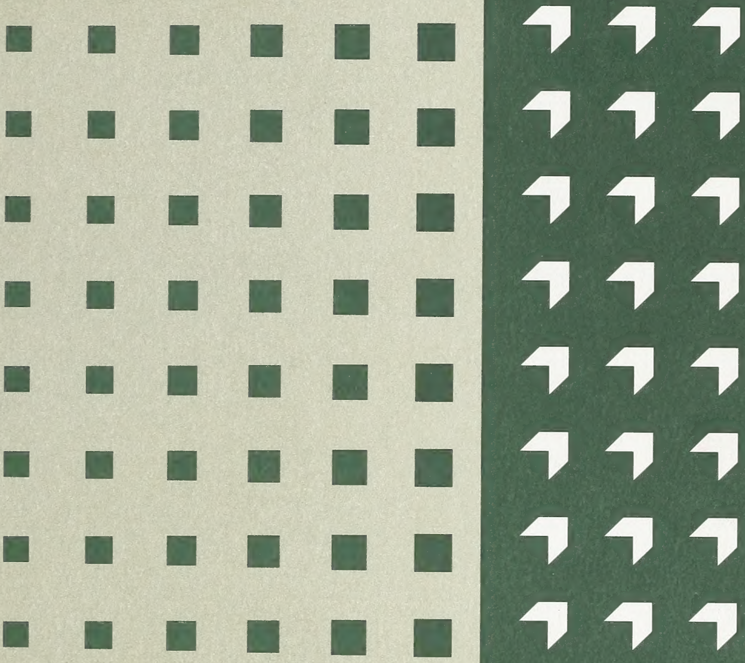
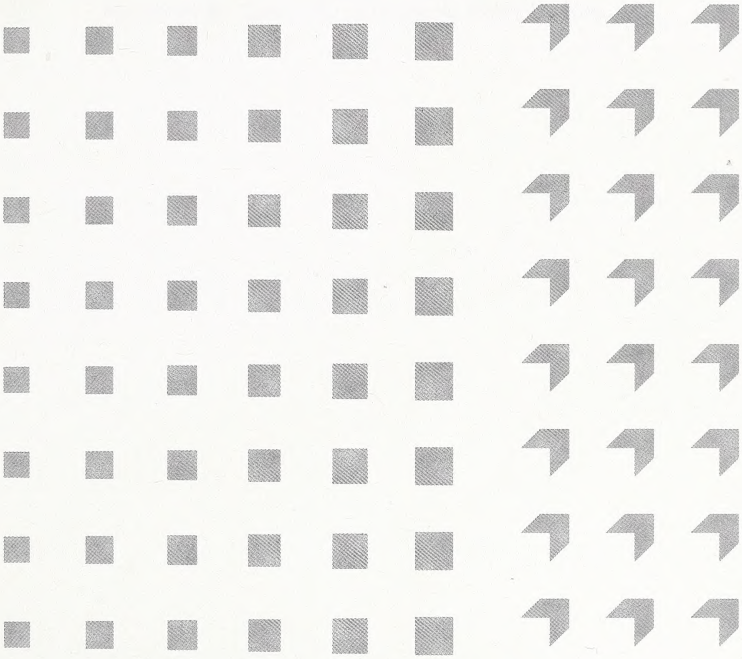


Alberta
ENERGY
Research and Technology
Branch

# Hydrogen Technology Research Program

# Annual Review 1990/91



Alberta
ENERGY
Research and Technology Branch

ISSN 1188-1291
ISBN 0-86499-867-8
Pub. No. 1/434

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# DIRECTOR'S REPORT

During the third week of July 1990, the Eighth World Hydrogen Energy Conference was held in Hawaii. The printed proceedings that resulted fill three textbook-size volumes amounting to more than 1600 pages. If these proceedings can be taken as a reliable indicator, more than 22 countries have active research programs in hydrogen, and it is quite clear that countries not normally regarded as economic powerhouses, such as India, Bangladesh and Romania, are acting now to stake out their share of what is being promoted as the fuel of the 21st century.

Albertans are participating in this activity as well, albeit in a modest way. The Hydrogen Technology Research Program has now completed its second full year of operation, with a total of 18 research projects initiated. All these projects relate directly to the production or use of hydrogen in the current petroleum and petrochemical industries of Alberta. After all, helping to make these industries more efficient is the principal objective of the program. Of equal importance, more efficient use of hydrogen will help accomplish optimal use of resources in an environmentally acceptable manner.

The conference in Hawaii showed that scientists in many countries are already looking beyond their existing economic situation and are beginning to put together technologies that may dominate the energy scene 20 to 50 years from now. It was interesting to note, for example, that less than a dozen of the 137 conference papers were related to the ways that hydrogen is used in Alberta, namely in the synfuel or chemical industries. The remaining papers concerned hydrogen production by electrolysis of water, hydrogen liquefaction, and the use of hydrogen in combustion systems, engines and fuel cells. This activity in areas well beyond the interests and requirements of the fossil fuel industry adds credence to the claim made in the foreword of the proceedings that "it is only a matter of time when hydrogen will start replacing fossil fuels on a large scale." For Alberta, this can be taken as either a threat or a challenge.

It is equally interesting to observe that countries participating in hydrogen research are not restricted to those that already have a huge fossil fuel industry and associated infrastructure, or massive hydro-electric resources. Although the U.S.A. and the former U.S.S.R. are major players, it is worth noting that work is under way in some Third World countries to make hydrogen from renewable sources like whey and molasses.

These are exciting times for hydrogen researchers. The Alberta program has made a good start, and some worthwhile advancements have been made during the past two years. It is particularly gratifying to have had excellent co-operation from industry in this program.

Thus far, the program has shown that Alberta has skilled, talented researchers able to undertake hydrogen studies with competence and confidence, and the industrial infrastructure and experience to turn laboratory discoveries into everyday reality. It remains to be seen whether we also have the vision and dedication to the future of hydrogen energy in Alberta to finish the job.

M.E. Torres
Director, Hydrogen Research and Technology

# INTRODUCTION

During 1987/88, a study to quantify current hydrogen production and consumption in Alberta revealed that Alberta industries produce 55 per cent and consume 63 per cent of all the hydrogen in Canada.

It was noted that most of the expected growth in hydrogen use is expected to arise from upgrading of heavy oil and bitumen. Because the costs of hydrogen production currently represent a significant portion of overall upgrading costs, and the energy industry had previously expressed interest in working with government to lower these costs, a joint industry/ government hydrogen technology research and development program was initiated in 1988/89. It was funded on a cost-shared basis by the Alberta/ Canada Energy Resources Research Fund (A/CERRF) and industry.

Currently, the program comprises the following components, each of which is considered to represent an aspect of hydrogen technology that requires commercial-scale development within 10 years. The components are:

- advanced or alternative hydrogen production technologies;
- production technologies that work synergistically with those being developed in a separate coal research program;
- hydrogen separation technologies;
- large volume hydrogen storage;
- transportation/distribution of hydrogen;
- optimum end-uses of hydrogen; and
- materials and safety technology.

During 1989/90, eight research projects were initiated, two of which were completed. In 1990/91, nine new projects were added to those that were continued. Including the hydrogen technology inventory study that was completed in 1988, 18 projects have been funded thus far.

The following section, Review of Program Projects — 1990/91, provides detailed information about individual projects and their achievements. The financial aspects of past and present projects are found in Appendix B.

# REVIEW OF PROGRAM PROJECTS — 1990/91

## Hydrogen Production

Water ($H_2O$), methane ($CH_4$) and hydrogen sulphide ($H_2S$) are considered to be the three primary sources for hydrogen production in the immediate future in Alberta. This does not imply that all other potential sources are excluded, but rather that these three feedstocks represent the richest, cheapest and most readily available sources.

In western Canada, steam-methane reforming (SMR) is the most important and best developed hydrogen production method, but it is not necessarily the least expensive option for Alberta. It also generates carbon dioxide as a by-product, a fact that is of some concern in a world worried about atmospheric warming.

Nonetheless, whenever alternative hydrogen production technologies are proposed, they are compared to SMR. This requires evaluation of several factors, including process chemistry, energy input, process engineering, product separation and purification, and by-product uses.

In the following section on hydrogen production research, seven projects are described. All represent attempts to develop new or improved hydrogen-producing systems that have commercial potential in the near future.

Thus far, all these investigations have focused on making hydrogen from hydrogen sulphide. There are four very good reasons for this: the gas is abundant in Alberta; it must undergo some form of treatment before it is released to the environment; the current treatment method recovers only one of the two possible commodities; and hydrogen production from hydrogen sulphide would not result in the release of carbon dioxide. This latter characteristic, which is common to processes that electrolyse water to make hydrogen and oxygen, is often touted as the principal advantage of electrolysis over SMR.

### CONVENTIONAL SOURCES OF HYDROGEN

$$H_2O \xrightarrow{\text{Electrolysis}} H_2 + \tfrac{1}{2}O_2$$

$$CH_4 + 2H_2O \xrightarrow{\text{Steam-Methane Reforming}} CO + 3H_2 + H_2O \xrightarrow{\text{Shift Conversion}} CO_2 + 4H_2$$

$$C + 2H_2O \xrightarrow{\text{Coal Gasification}} CO + H_2 + H_2O \xrightarrow{\text{Shift Conversion}} CO_2 + 2H_2$$

## A Claus Plant Modification for Hydrogen Production[1]

ALBERTA SULPHUR RESEARCH LTD., CALGARY

Hydrogen sulphide gas is commonly found in Alberta's natural gas, and is also present in the "off gas" produced by upgraders at Alberta refineries. Because hydrogen sulphide can be toxic at low concentrations, it must be treated before it can be released to the atmosphere. This treatment occurs in plants using the Modified Claus Process. They convert $H_2S$ to elemental sulphur by a sequence of combustion and catalytic steps. The primary product of this reaction, sulphur, is a valuable commodity. Currently, more than five million tonnes of sulphur are produced annually in Alberta using this technology. All the hydrogen present in $H_2S$ ends up in the other product of the Modified Claus Process — water.

Since Modified Claus plants are scattered throughout Alberta, it was proposed by Alberta Sulphur Research Ltd. that they be used to produce sulphur and hydrogen instead of sulphur and water. The objective of a project initiated in 1989 is to develop technology allowing the high temperatures available in a typical Claus furnace to be used for direct thermal decomposition of a portion of the hydrogen sulphide feed to Modified Claus plants. This would produce hydrogen along with sulphur. Not only would this provide a method for producing hydrogen as an additional commodity from the hydrogen sulphide stream, but a necessary requirement of this approach is that current Claus plant economics not be affected.

During the first six months of the project, more than 100 laboratory experiments were conducted to determine the effect of various reaction conditions on thermal cracking efficiency. Significant yields of hydrogen were obtained at temperatures as high as 1 200°C. These temperatures are consistent with normal Claus operations. It was found that residence times and reaction quench times were critical for optimising the hydrogen yield.

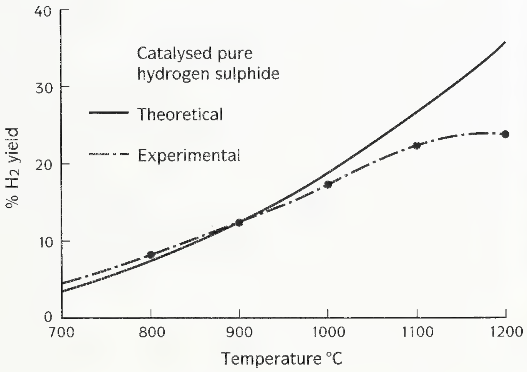
In particular, a special sampling procedure was developed to allow quench times in the order of 20 to 30 milliseconds. This effectively prevented hydrogen-consuming back reactions from occurring.

Because some carbon dioxide is likely to accompany hydrogen sulphide in feed gas mixtures, thermal decomposition studies were conducted using $H_2S/CO_2$ mixtures in the presence or absence of catalysts. Results indicated that small amounts of carbon dioxide (up to 10 per cent) can be tolerated without any adverse affect on the hydrogen yield, but when $CO_2$ was present in amounts approximating 30 per cent of the mixture, the hydrogen yield was measurably lower. When a catalyst was present, it was affected adversely as well. The extent of the effect was influenced by temperature.

During 1990/91, additional thermal cracking experiments were carried out, resulting in even higher yields of hydrogen under some conditions. This provided additional evidence of the importance of short quench times. Also, further testing was done to establish the best balance among the catalyst, temperature and carbon dioxide content.

A computer model was developed to examine the effects of varying certain process characteristics, such as feed gas composition, distribution of feed gases between the thermal cracking unit and the normal Modified Claus plant, and pre-treatment of the feed to the thermal cracker. The results will be used in the engineering design for a proposed pilot-scale thermal cracker. A number of secondary effects are also being modelled. The results to date are showing how operating conditions can be designed to optimise the hydrogen yield from a Modified Claus plant, while minimising any adverse effects on the operating efficiency of the current Claus systems.

Equilibrium per cent hydrogen yield vs temperature
($2H_2S \rightleftharpoons 2H_2 + S_2$)



Source: Alberta Sulphur Research Ltd.

A typical Modified Claus plant at a sour gas processing facility.

As it is apparent that development of a separation technique to recover hydrogen is essential, work was begun on a high-temperature membrane system. Some encouraging results were obtained from microporous alumina ceramic membranes that had been impregnated with sodium silicate.

This project will continue next year.

[1] The project received financial support from Alberta Sulphur Research Ltd. and A/CERRF.

## Conversion of Hydrogen Sulphide to Hydrogen and Organosulphur Compounds by Metal Catalysts[1]

ALBERTA SULPHUR RESEARCH LTD., CALGARY

This project was initiated during 1989, with the objective of investigating methods for using hydrogen sulphide to produce hydrogen and commercially valuable chemicals derived from sulphur. Specifically, the objectives are to:

- confirm reports in the literature that metal complexes can split $H_2S$ into hydrogen and metal-combined sulphur at ambient conditions;
- determine the feasibility of converting the metal-combined sulphur to industrially important organosulphur chemicals; and
- examine the feasibility of recycling the metal complexes for use in further dissociation reactions.

Ruthenium and nickel compounds were prepared and used to liberate hydrogen from hydrogen sulphide. While the ruthenium compounds reacted well with $H_2S$ and produced significant quantities of hydrogen, they were difficult to purify and reuse. The nickel compounds were found to be highly reactive with hydrogen sulphide, but the sulphur-containing reaction products tended to decompose too quickly for practical recovery. Complexes containing palladium were then prepared and tried. The use of one of these led to thermally unstable products that did not contain sulphur, while another failed to react with hydrogen sulphide.

It was concluded that metal complexes do react with $H_2S$ under mild conditions to produce good yields of hydrogen. However, more basic research is needed on the sulphur-containing by-products before such processes can be considered as foundations for industrial processes.

*Publications*

Clark, P.D. 1991. Investigations Into the Conversion of $H_2S$ to $H_2$ and Organosulphur Compounds by Metal Catalysis. Final Report. Alberta Sulphur Research Ltd.

Clark, P.D. and B. Wassink. 1990. A Review of Methods for the Conversion of $H_2S$ to Sulphur and Hydrogen. In: Alberta Sulphur Research Ltd. Quarterly Bulletin, XXVI:1-77. Alberta Sulphur Research Ltd.

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[1] The project was funded by Alberta Sulphur Research Ltd. and A/CERRF.

# Production of Hydrogen and Sulphur from Hydrogen Sulphide[1]

UNIVERSITY OF ALBERTA/CANMET,
EDMONTON/DEVON

Researchers at the University of Alberta and the Coal Research Laboratories of CANMET investigated methods for possible commercial production of hydrogen and sulphur from hydrogen sulphide. Two approaches were used: (1) the electrolysis of liquid or aqueous hydrogen sulphide, and (2) the reaction of $H_2S$ with copper to produce hydrogen and copper sulphide, followed by treatment of the copper sulphide to obtain copper for recycling and elemental sulphur.

Electrochemical experiments on hydrogen sulphide in aqueous diethanolamine or sodium hydroxide were successful in producing hydrogen with good electrical current efficiency. Yields of sulphur were low, however, and separating sulphur from solution was difficult. The yields of sulphur rose when a two-phase mixture of an alkaline aqueous solution of $H_2S$ and an immiscible organic solvent was used.

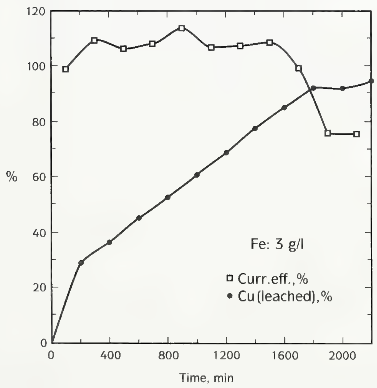
When gaseous hydrogen sulphide was reacted with copper, essentially 100 per cent conversion of hydrogen sulphide to hydrogen was achieved under practical operating conditions. Experiments on the electrochemical leaching of copper sulphide to obtain sulphur and metallic copper (for recycling) led to recovery of more than 90 per cent of the sulphur and nearly 100 per cent of the copper.

A high-pressure cell constructed for studies of the electrolytic decomposition of liquid hydrogen sulphide at room temperature was eventually replaced by another cell designed at McMaster University. This cell was used to make conductivity measurements of liquid $H_2S$. At year-end, a report on these experiments was being prepared.

*Publication*

Chen, Q., L. Li and L.G. Hepler. 1990. Kinetics of Desulfurization of Hydrogen Sulfide Using Metallic Copper as a Desulfurizer. Accepted for publication in Can. J. Chem. Eng.

Current efficiency and percentage of leached copper from cuprous sulphide



Source: Chen, Q., L. Li and L.G., Hepler. 1991. Investigation on the Recoveries of Elemental Sulfur and Metallic Copper from Cuprous Sulfide. Departments of Chemistry and Chemical Engineering, University of Alberta.

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[1] Funded entirely by A/CERRF.

# High-Temperature Electrolysis of Aqueous Hydrogen Sulphide for the Production of Hydrogen and Molten Sulphur[1]

ALBERTA RESEARCH COUNCIL, EDMONTON

An alternative approach involving electrolysis of aqueous hydrogen sulphide was investigated at the Alberta Research Council. The objective was to overcome some of the limitations encountered by previous investigators at ambient temperatures. In these earlier experiments, it was found that produced sulphur collected on the anode of the electrolysis apparatus, reducing the rate of hydrogen sulphide conversion to hydrogen and sulphur. Also, the sulphur quality was poor.

In this project, the objective was to conduct electrolysis experiments at temperatures above the melting point of sulphur, allowing the sulphur to drain from the anode and be recovered for further treatment.

Initially, experiments were carried out at 25°C and 80°C in both acidic and alkaline solutions to duplicate the experiments reported in the scientific literature, and establish some baseline conditions for future work. While approximately 90 to 100 per cent of the theoretical hydrogen was produced, only small quantities of sulphur were formed, which deposited on the anode as expected.

The next series of experiments was designed, taking into consideration the need to strike a balance between acceptable production levels of hydrogen and sulphur, and practical operating conditions.

Experiments at higher temperatures and pressures showed promising results. Using sulphuric acid to achieve a pH of 1.0, and employing a temperature of 138°C and a pressure of 250 psi $H_2S$, the yields of sulphur and hydrogen were 54 and 82 per cent, respectively, of the theoretical amounts. The solid product was identified as orthorhombic sulphur. Also, the required current densities were approximately one-half or less than one-half those used when water is electrolysed commercially.

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[1] The project was funded jointly by Alberta Research Council and A/CERRF.

Schematic drawing of electrolysis cell and associated equipment

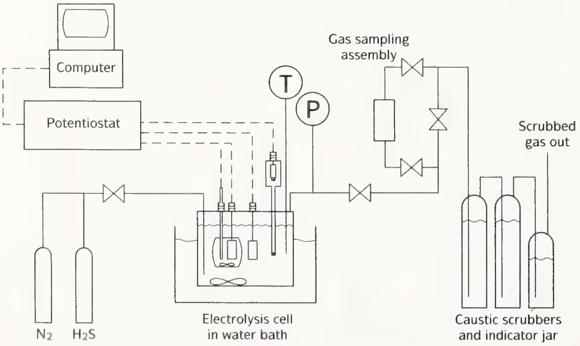

Illustration courtesy of Alberta Research Council

# Chemically Modified Electrodes for Hydrogen Sulphide Electrolysis[1]

ALBERTA RESEARCH COUNCIL, EDMONTON

The direct electrolysis of hydrogen sulphide is regarded by some researchers as the best potential method for producing hydrogen and sulphur on a commercial scale, but sulphur deposition on the anode continues to be a problem. While some researchers claim to have overcome "anode blocking", they did it using electrical currents that are far too low for industrial requirements.

In a project initiated at the Alberta Research Council, the objective was to develop highly catalytic, surface-modified electrodes that will lead to rapid transfer of electrons without sulphur deposition.

The following electrodes were tested:

- platinum, gold, nickel and glassy carbon;
- carbon paste; and
- carbon paste modified with different zeolites and catalysts.

As has been observed by other researchers, the platinum, gold and nickel electrodes were soon blocked by deposited sulphur, but the glassy carbon electrode was capable of maintaining a stable voltage for 24 hours, indicating it was less affected by sulphur deposition.

Based on the positive results from the glassy carbon electrodes, carbon paste electrodes modified with zeolites were prepared and tested. They demonstrated superior performance relative to the unmodified electrodes, and this performance was enhanced when catalysts were incorporated in the zeolite structure.

Cobalt phthalocyanine incorporated in a Y-zeolite electrode was shown to be capable of producing four times as much sulphur as any other electrode studied in this investigation. During 24 hours of electrolysis, this type of electrode operated at current densities that approximated 100 $mA/cm^2$ of its macroscopic surface area. These results were further improved by raising the reaction temperature from 25° to 70°C.

The results indicated that sulphur deposition was not occurring on the electrode surface, and incorporation of the catalyst helped shift the reaction toward the formation of ionic products, thus facilitating the electrolysis step.

*Publication*

Petrovic, S. 1991. Chemically Modified Electrodes for the Electrolytic Production of Hydrogen and Sulphur from Hydrogen Sulphide. Alberta Research Council.

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[1] The project was funded jointly by Alberta Research Council and A/CERRF.

## The Carbon Monoxide Catalysed Conversion of Hydrogen Sulphide to Hydrogen and Sulphur[1]

UNIVERSITY OF ALBERTA, EDMONTON

An alternative to electrolysis or thermal conversion of hydrogen sulphide to obtain hydrogen was explored in this project. The objective was to produce hydrogen from a two-step reaction between hydrogen sulphide and carbon monoxide, and then regenerate carbon monoxide for reuse.

Using a NiS/alumina catalyst, one atmosphere pressure and a reaction temperature of 253°C, conversions to hydrogen and carbonyl sulphide, which represented up to 94 per cent of the thermodynamic equilibrium value, were achieved according to the following reaction:

$$H_2S + CO \rightleftharpoons H_2 + COS$$

A second reaction step was proposed to convert carbonyl sulphide to elementary sulphur, as follows:

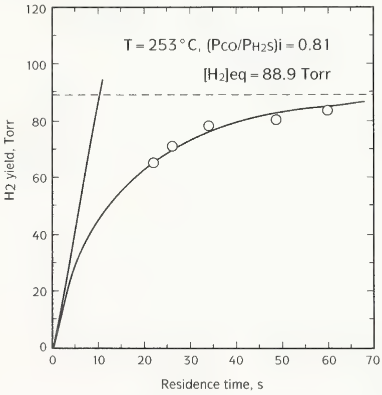
$$COS \rightleftharpoons CO + S$$

Initial work with this reaction was promising, but there was insufficient time to pursue it further. At the conclusion of the A/CERRF-supported phase of this project, research funds from another source had been obtained to continue studying this reaction step.

*Publication*

Strausz, O.P. 1991. The CO-Catalyzed Conversion of $H_2S$ to $H_2$ and S. University of Alberta.

**The dependence of hydrogen yield on residence time**



Source: Stausz, O.P. 1991. The CO-Catalyzed Conversion of $H_2S$ to $H_2$ and S. University of Alberta.

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[1] Funding was provided by Gulf Canada Resources Limited and A/CERRF.

## Cold Plasma Decomposition of Hydrogen Sulphide[1]

SHELL CANADA LIMITED (CALGARY) AND ATOMIC ENERGY OF CANADA LIMITED RESEARCH COMPANY (CHALK RIVER)

In this project, conducted by Atomic Energy of Canada Limited (AECL) in collaboration with Shell Canada Limited, microwave energy was used to initiate and maintain a “cold plasma” of hydrogen sulphide. In this state, hydrogen sulphide can be decomposed into its elemental components, hydrogen and sulphur.

In studies reported in the scientific literature, successful decomposition of hydrogen sulphide has been proven, but at conditions that would not be practical for large-scale, commercial operations. Thus, one objective of the AECL project was to investigate the microwave-induced decomposition of hydrogen sulphide at pressures that are more suitable for commercial use.

A special apparatus was designed and constructed for this project. It included a system for efficient removal of sulphur formed during the decomposition reaction, and a method for recirculating any unreacted hydrogen sulphide.

Hydrogen sulphide was converted to hydrogen and sulphur at various flow rates. At low gas flow rates, the decomposition yield was as high as 60 per cent. Also, effects of the feed gas contaminants, methane and carbon dioxide, were measured on the percentage decomposition, product formation and the electric field at the plasma. The percentage decomposition of $H_2S$ was maintained in the presence of carbon dioxide and increased in the presence of methane.

Although this work was supported by A/CERRF for only one year, the investigation will continue. A low frequency source, developed during this project, will be used to generate the plasma.

*Publication*

Cold Plasma Decomposition of Hydrogen Sulphide. 1991. AECL Research/Shell Canada Limited.

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[1] The project was funded by Shell Canada Limited, Atomic Energy of Canada Limited and A/CERRF.

# Hydrogen Separation

Separation of produced hydrogen from unreacted feedstock or reaction by-products is one aspect of the Alberta Hydrogen Technology Research Program that deserves special attention.

Although several straightforward hydrogen separation methods exist, use of these technologies in combination with thermally or chemically energized hydrogen production processes is often inefficient. This is frequently caused by large changes in the process temperature and pressure.

Also, some existing hydrogen-producing processes might become economically attractive if they could be combined with suitable separation methods.

For these reasons, one hydrogen separation project was initiated during 1989/90 and another was begun in 1990/91. Both are described in the following section.

## Hydrogen Separation and Purification[1]

ALBERTA RESEARCH COUNCIL, EDMONTON

The removal of impurities from hydrogen usually requires a combination of several separation techniques, making the process cumbersome and inefficient. Consequently, in this project, an integrated permeation/sorption separation system is being developed, using hollow-fibre technology. It is believed this could lead to smaller and more efficient separation devices.

Last year, a hollow-fibre separation system was constructed, and an automated "pressure swing adsorption" system was built to test the hollow-fibre device for hydrogen separation and purification.

Since then, a detailed investigation of the sorption and permeation components of the system has been completed. The test program showed that hydrogen can be separated effectively, and the most important advantage of the system is its ability to accomplish this level of hydrogen separation at high rates of feed gas passage through the unit.

Extensive tests employing a bench-scale pressure swing adsorption device, along with zeolite crystals and activated carbon powder, showed that even a small module can process large volumes of feed gas.

While the process produces ultra-high purity hydrogen, recovery rates are lower than desired. This is the result of cyclic pressurization and depressurization steps. A novel pressure swing membrane permeator has been designed to accommodate these changes in pressure.

A mathematical model of the hollow fibre pressure swing adsorption process was developed. It was used to help analyse and optimize the process.

Hollow fibre adsorber for Pressure Swing Adsorption

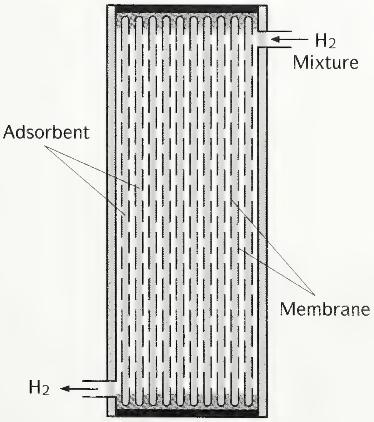

Illustration courtesy of Alberta Research Council

*Publication*

Pan, C.Y., E. Hadfield and C. McMinis. 1991. Final Technical Report on Hydrogen Separation and Purification. Alberta Research Council.

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[1] Funded jointly by Alberta Research Council and A/CERRF.

## High-Temperature Separation of Hydrogen Using Novel Ceramic Membranes[1]

ALBERTA RESEARCH COUNCIL, EDMONTON

In recent years, ceramic membranes based on porous metal oxides, such as alumina, have demonstrated characteristics that make them attractive for high-temperature separation of gas mixtures. Compared with polymeric membranes, they have a higher thermal stability, can operate at higher pressures, and have a longer life and higher permeability. They are substantially more expensive, however.

Thus, a project was begun this year at the Alberta Research Council to develop porous ceramic membranes having controlled pore sizes that are sufficiently small to allow only hydrogen molecules to pass. Following a literature search on membranes that use zeolite composites, work began on preparing test membranes coated with either alumina (aluminum oxide) or one type of zeolite (hydrated aluminosilicate) composite.

*Publication*

Smith, K.J and L. Johanson. 1991. Development of Ceramic Membranes for High Temperature Separation of Hydrogen. A Review. Alberta Research Council.

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[1] Funded by Shell Canada Limited, Alberta Research Council and A/CERRF.

## Infrastructure and Storage/Transportation

The net hydrogen surplus currently existing at some Alberta facilities or locations is expected to become larger as new or improved hydrogen production technologies are introduced. Fortunately, this surplus is expected to be offset by expansion of bitumen upgrading, increased synthetic fuel production and growth in the production of some specialty chemicals. All of these will consume hydrogen.

Thus, there is a need to move hydrogen from locations where it is produced in excess of on-site demand to those places where it is not produced but is needed. This entails some method for integrating producers and consumers.

Before an integrated producer/consumer network can be established, however, numerous technical issues must be addressed. One of the first requirements is for a strategy to link producers with consumers, including a staged development scheme.

Of equal importance is the necessity for investigations of several storage and transportation elements. These will depend on the physical state of hydrogen when it is stored or transported, and must recognize that hydrogen could be handled as a gas or a liquid.

Transportation of hydrogen could involve some combinations of truck, rail and pipeline. Like storage, this would require investigation of certain safety aspects and the physical effects of hydrogen on the storage or transportation medium.

During 1989/90, two studies related to these issues were undertaken and completed. In one, a computerized method for integrating hydrogen producers and consumers was developed at the Alberta Research Council. In the other study, a preliminary engineering investigation was made of the concept of storing hydrogen in salt caverns. Both of these studies produced positive and encouraging results and paved the way for one additional study that was carried out during 1990/91. This latest investigation is described in the following section.

## Hydrogen Transportation Using Present Pipeline Networks[1]

HYDROGEN INDUSTRY COUNCIL, CALGARY

An important component of Alberta's hydrogen research program is having the ability to transport hydrogen to markets in an economically and technically sound manner. As the demand for hydrogen grows, this need will become more urgent.

It is believed that hydrogen can be transported along with natural gas in the existing natural gas pipeline network that extends throughout much of Canada and the United States. Studies carried out thus far have indicated that transportation of gas/hydrogen mixtures is feasible, and only minor adjustments to mechanical systems are required to accommodate hydrogen.

The objective of this project, which was initiated late in the year, is to investigate the market potential for hydrogen/natural gas mixtures that are transported in existing pipelines. The economics of the concept will be examined in terms of hydrogen sources and uses. As well, a number of technical issues will be addressed, including any adverse effects of gas mixtures on the mechanical integrity of pipelines and pumping equipment.

At year-end, the project had been divided into seven components, and sub-contractors had been hired to investigate each. Items being studied include: the thermodynamic and combustion properties of hydrogen; purification, pipelining, storage and compression of hydrogen gas; fuel cell applications; and collection, distribution and uses for hydrogen in Alberta and beyond.

[1] Funding was provided by Gulf Canada Resources Limited, Northwestern Utilities Limited, Union Carbide Canada Limited, OSLO Alberta Limited (as agent for the OSLO Participants, namely Petro-Canada Inc., Alberta Oil Sands Equity, Pan Canadian Petroleum Limited, Esso Resources Canada Limited, Canadian Occidental Petroleum Ltd. and Gulf Canada Limited), Hydrogen Industry Council (project operator) and A/CERRF.

## Hydrogen Use

Although oil refining and synthetic crude oil production rank among the largest uses for hydrogen in Alberta, even greater quantities are used by fertilizer and methanol producers. Hydrogen is also consumed in the manufacture of chemicals and pharmaceuticals, and it is important in steel making and metallurgy. Thus, the Alberta Hydrogen Technology Research Program encompasses all possible uses for hydrogen in the province, with equal emphasis on improving the efficiency of current hydrogen-consuming processes and finding new uses for hydrogen in Alberta.

Two research projects related to this aspect of the program were initiated during 1990/91.

## Optimization of Hydrogen Utilization in Heavy Hydrocarbon Processing[1]

ALBERTA CHAMBER OF RESOURCES, EDMONTON

One of the original premises of Alberta's Hydrogen Technology Research Program was that Canada will need more crude oil from non-conventional sources, such as the oil sands, as reserves of conventional light and medium crude oils decline. In turn, this will create a greater demand for hydrogen, which is used to upgrade synthetic crude oils to refinery-acceptable feedstocks.

To keep the costs of upgrading as low as possible, it is necessary that the current methods of using hydrogen be made more cost efficient, or new ways of using hydrogen be found.

Thus, in a project co-ordinated by the Oil Sands Task Force of the Alberta Chamber of Resources, and begun this year by RTM Engineering Ltd., the objective is to review and then select new or emerging technologies that have demonstrated some promise for improving the use of hydrogen in upgraders and refineries. Also, the study is updating the hydrogen inventory study completed in 1988.

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[1] Funded jointly by Alberta Chamber of Resources and A/CERRF.

## Refinery By-product Hydrogen Use for Electricity Generation in Fuel Cells[1]

TRANSALTA UTILITIES CORPORATION, CALGARY

Currently, approximately 25 per cent of the hydrogen produced in Alberta exceeds the requirements of the producing company for use in the petroleum and petrochemical industries. As a result, the excess hydrogen is either used as a fuel or is burned in on-site flare stacks. While a provincial network for distributing surplus hydrogen would reduce this practice substantially, hydrogen produced in remote locations probably would not enter the distribution system. Thus, in this project, the option of using hydrogen in fuel cells to produce electricity at a refinery was explored by TransAlta Utilities Corporation. The investigation was subcontracted to RTM Engineering Ltd.

In reviewing the state-of-the-art of fuel cells, it was concluded that fuel cell technology has been advancing rapidly and demonstration of industrial-scale units is expected soon. If such technology becomes economically attractive on a commercial scale, it is likely that applications would arise in Alberta. Currently, however, this is not the case.

This conclusion was reached after examining the economics of using phosphoric acid fuel cells developed by Westinghouse, which are regarded as being the closest to commercial use. It was found that these fuel cells cannot be used economically in a refinery at present. The unit capital costs must be lowered and the value of electricity must be raised before fuel cells using hydrogen to produce electricity would become attractive in Alberta. The convergence of these two events is thought to be five years away, at least.

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[1] Funded jointly by TransAlta Utilities Corporation and A/CERRF.

FUEL CELL ELECTROCHEMISTRY

$$H_2 + \tfrac{1}{2}O_2 \dashrightarrow H_2O \quad \text{emf} = 0.812\,\text{v}$$

## Other

### Hydrogen Technology Program Planning and Implementation Assistance

HAROLD V. PAGE, EDMONTON

The services of a consultant were retained on a part-time basis by the Alberta Department of Energy to assist in planning and implementing the Hydrogen Technology Research Program. The consultant negotiated research contracts, oversaw the progress of all hydrogen research projects initiated thus far, provided administrative services for various committees and organized hydrogen research workshops. Proposals for hydrogen research projects were reviewed and recommendations were made to the A/CERRF Committee for project funding.

### University of Calgary Hydrogen Industry Chair

THE UNIVERSITY OF CALGARY, CALGARY

A position at The University of Calgary is being established with a grant from A/CERRF and some industry participants[1] to conduct hydrogen research that will be of direct benefit to the industry partners.

[1] Currently, research funds from A/CERRF are being matched by the following group of industry participants: Shell Canada Limited, Esso Resources Canada Limited, Husky Oil, Gulf Canada Limited, AMOCO Canada Petroleum, TransAlta Utilities Corporation and Alberta Oil Sands Technology and Research Authority. The University of Calgary is contributing the salary of one professor.

# APPENDICES

All research projects supported by the Hydrogen Technology Research Program are listed in Appendix A, while information about the funding provided by A/CERRF is found in Appendix B.

# Appendix A

Complete Listing of Projects Supported by the Hydrogen Technology Research Program

## Hydrogen Production

| Project | Researcher | Status |
|---|---|---|
| Examination of the Partial Oxidation of Methane for the Production of Hydrogen and/or Synthesis Gas | G.A. Karim, The University of Calgary, Calgary | Completed in 1989/90 |
| A Claus Plant Modification for Hydrogen Production | Alberta Sulphur Research Ltd., Calgary | Continuing |
| Conversion of Hydrogen Sulphide to Hydrogen and Organosulphur Compounds by Metal Catalysts | Alberta Sulphur Research Ltd., Calgary | Completed in 1990/91 |
| Production of Hydrogen and Sulphur from Hydrogen Sulphide | L.G. Hepler, University of Alberta, Edmonton and J. Donini, CANMET, Devon | Completed in 1990/91 |
| High-Temperature Electrolysis of Aqueous Hydrogen Sulphide for the Production of Hydrogen and Molten Sulphur | Alberta Research Council, Edmonton | Completed in 1990/91 |
| Chemically Modified Electrodes for Hydrogen Sulphide Electrolysis | Alberta Research Council, Edmonton | Continuing |
| The Carbon Monoxide Catalysed Conversion of Hydrogen Sulphide to Hydrogen and Sulphur | O.P. Strausz, University of Alberta, Edmonton | Continuing |
| Cold Plasma Decomposition of Hydrogen Sulphide | Shell Canada Limited and Atomic Energy of Canada Limited, Calgary and Chalk River | Completed in 1990/91 |

| Project | Researcher | Status |
|---|---|---|
| **Hydrogen Separation** | | |
| Hydrogen Separation and Purification | Alberta Research Council, Edmonton | Completed in 1990/91 |
| High-Temperature Separation of Hydrogen Using Novel Ceramic Membranes | Alberta Research Council, Edmonton | Completed in 1990/91 |
| **Infrastructure and Storage/Transportation** | | |
| Hydrogen Producer/ Consumer Network | Alberta Research Council, Devon | Completed in 1989/90 |
| Salt Cavern Storage of Hydrogen | RTM Engineering Ltd., Calgary | Completed in 1989/90 |
| Hydrogen Transportation Using Present Pipeline Networks | Hydrogen Industry Council, Calgary | Continuing |
| **Hydrogen Use** | | |
| Optimization of Hydrogen Utilization in Heavy Hydrocarbon Processing | Alberta Chamber of Resources, Edmonton | Completed in 1990/91 |
| Refinery By-product Hydrogen Use for Electricity Generation in Fuel Cells | TransAlta Utilities Corporation, Calgary | Completed in 1990/91 |
| **Other** | | |
| Hydrogen Technology Program Planning and Implementation Assistance | Harold V. Page, Edmonton | Completed in 1990/91 |
| University of Calgary Hydrogen Industry Chair | The University of Calgary, Calgary | Continuing |

# Appendix B

## Summary of Program Expenditures by A/CERRF

| PROJECT TITLE | 1987/88 | 1988/89 | 1989/90 | 1990/91 | Projected Future Funding 1991/92 | TOTAL |
|---|---|---|---|---|---|---|
| Hydrogen Technology Inventory Study for Alberta | 47 874 | - | - | - | - | 47 874 |
| Hydrogen Technology Program Planning and Implementation Assistance | - | 5 805 | - | - | - | 5 805 |
| A Claus Plant Modification For Hydrogen Production | - | - | 68 490 | 143 847 | 146 203 | 358 540 |
| Production of Hydrogen and Sulphur From Hydrogen Sulphide | - | - | 76 235 | 70 665 | - | 146 900 |
| Conversion of $H_2S$ to $H_2$ and Organosulphur Compounds by Metal Catalysts | - | - | 12 806 | 17 194 | - | 30 000 |
| Examination of the Partial Oxidation of Methane For Production of Hydrogen and/or Synthesis Gas | - | - | 58 391 | - | - | 58 391 |
| High-Temperature Electrolysis of Aqueous Hydrogen Sulphide | - | - | - | 60 000 | - | 60 000 |
| The CO-Catalyzed Conversion of $H_2S$ to $H_2$ | - | - | - | 81 640 | 13 800[b] | 95 440 |
| Cold Plasma Decomposition of Hydrogen Sulphide | - | - | - | 194 627 | 194 837[b] | 389 464 |
| Chemically Modified Electrodes For The Electrolytic Production of $H_2$ and S From $H_2S$ | - | - | - | 25 393 | 31 880[b] | 57 273 |
| Hydrogen Separation and Purification | - | - | 167 342 | 116 454 | - | 283 796 |
| High-Temperature Separation of Hydrogen Using Novel Ceramic Membranes | - | - | - | 58 511 | 78 184[b] | 136 695 |
| Salt Cavern Storage of Hydrogen | - | - | 43 071 | - | - | 43 071 |
| Hydrogen Producer/Consumer Network | - | - | 39 492 | - | - | 39 492 |
| Hydrogen Transportation Using Present Pipeline Networks | - | - | - | 56 324 | 78 176 | 134 500 |
| Optimization of Hydrogen Utilization In Heavy Hydrocarbon Processing | - | - | - | 93 246 | - | 93 246 |
| Refinery By-product Hydrogen Use For Electricity Generation In Fuel Cells | - | - | - | 15 075 | - | 15 075 |
| University of Calgary Hydrogen Chair | - | - | - | 375 000[a] | - | 375 000 |
| TOTAL: Hydrogen Technology Research Program | 47 874 | 5 805 | 465 827 | 1 307 976 | 543 080 | 2 370 562 |

[a] Advanced transfer of 375 000

[b] To be funded by the Department of Energy

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ISSN 1188-1291
ISBN 0-86499-867-8
Pub. No. 1/434

Printed on Recycled Paper